Challenges to the use of CFD in the Military Aircraft Industry

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Overview

- Industrial environment
- Types of problems that need to be addressed
- Challenge areas
- Summary

Environment

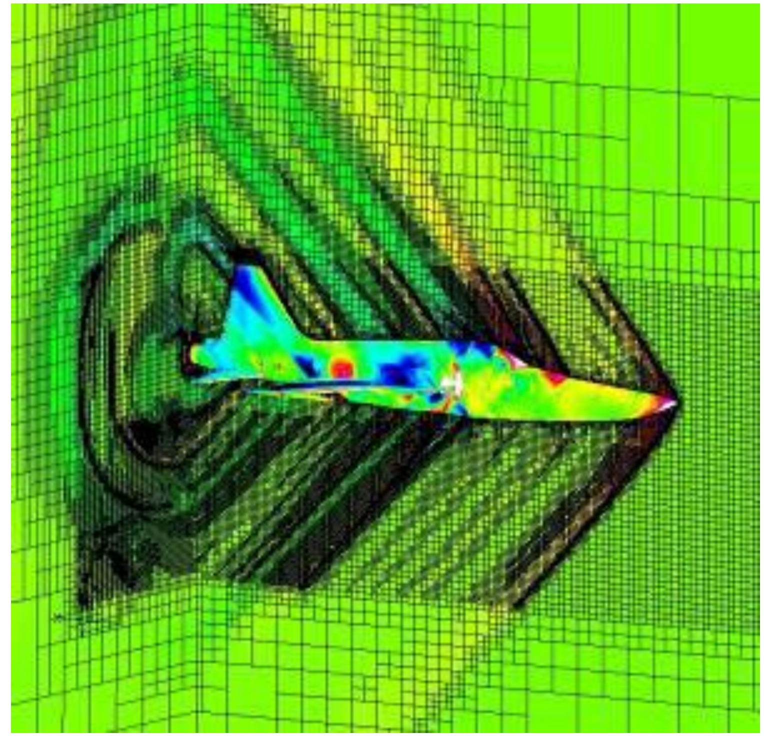
- Diverse problem set
  - Incompressible through hypersonic
  - External aerodynamic and internal (inlet, nozzle) flows
  - Range of aircraft (subsonic transport, transonic, fighters, ISR, hypersonic…
  - Range of complexity: components, conceptual, final design
- Large number of users with range of CFD competence
- Computational resources are often restricted – difficult to use massive parallel resources
  - Need to protect proprietary data
  - Small, compartmentalized programs
- CFD must buy its way into program application
  - Accurate enough to be relied on for design
  - Cost effective
  - Meet schedules

Diverse CFD Applications on Programs

- New Concepts
  - Radical new designs
  - Flow control (example: sweeping jets, synthetic jets)
- Design
  - Preliminary design – screen a design space
- Optimization
  - Optimize outer mold line for cruise conditions
  - Meet performance requirements
- Development
  - Off design
  - Databases: loads, S&C
  - Store separation
- Analysis of special cases
  - Ground test and flight test anomalies
  - Improvements and modifications

Conceptual Design Requires Tools that Can Rapidly Simulate Multiple Configurations

LM Aero Employs Splitflow for Conceptual Design



- Conceptual design methods for fast turnaround analysis
  - Many configurations need to be analyzed
  - Highest fidelity may not be required at this stage
  - Focus is frequently on cruise design points

Vortex Lattice

Full Potential

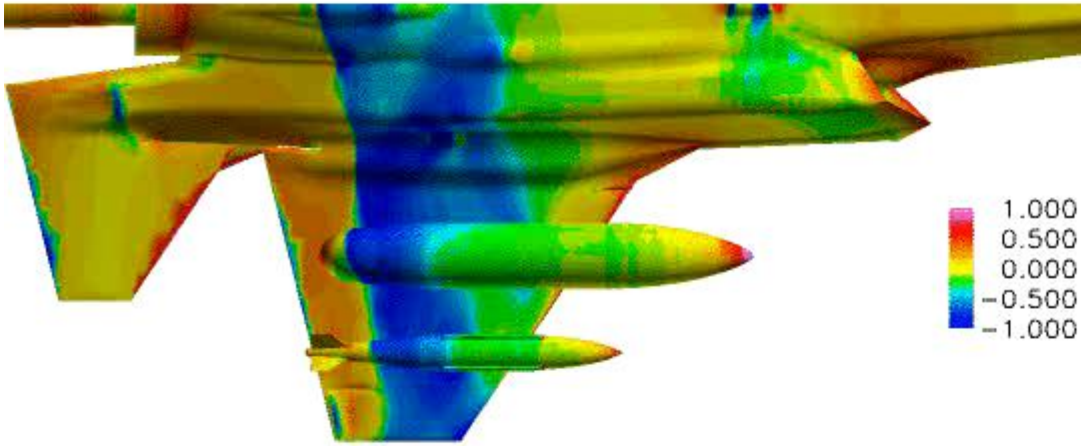
Euler

RANS

- A variety of methods can be applied depending on speed regime and accuracy desired
- Methods with automated grid generation can be extremely valuable for these applications

Optimization Requires Specialized Methods for Efficient Application

- **Optimization requires methods for automated geometry changes**
  - **Unstructured meshes**
  - **Cut cell methods**
- **Moderate levels of accuracy**
- **Computational efficiency is critical**



From Charlton and Davis, AIAA 2008-0376, "Computational Optimization of the F-35 External Fuel Tank for Store Separation"

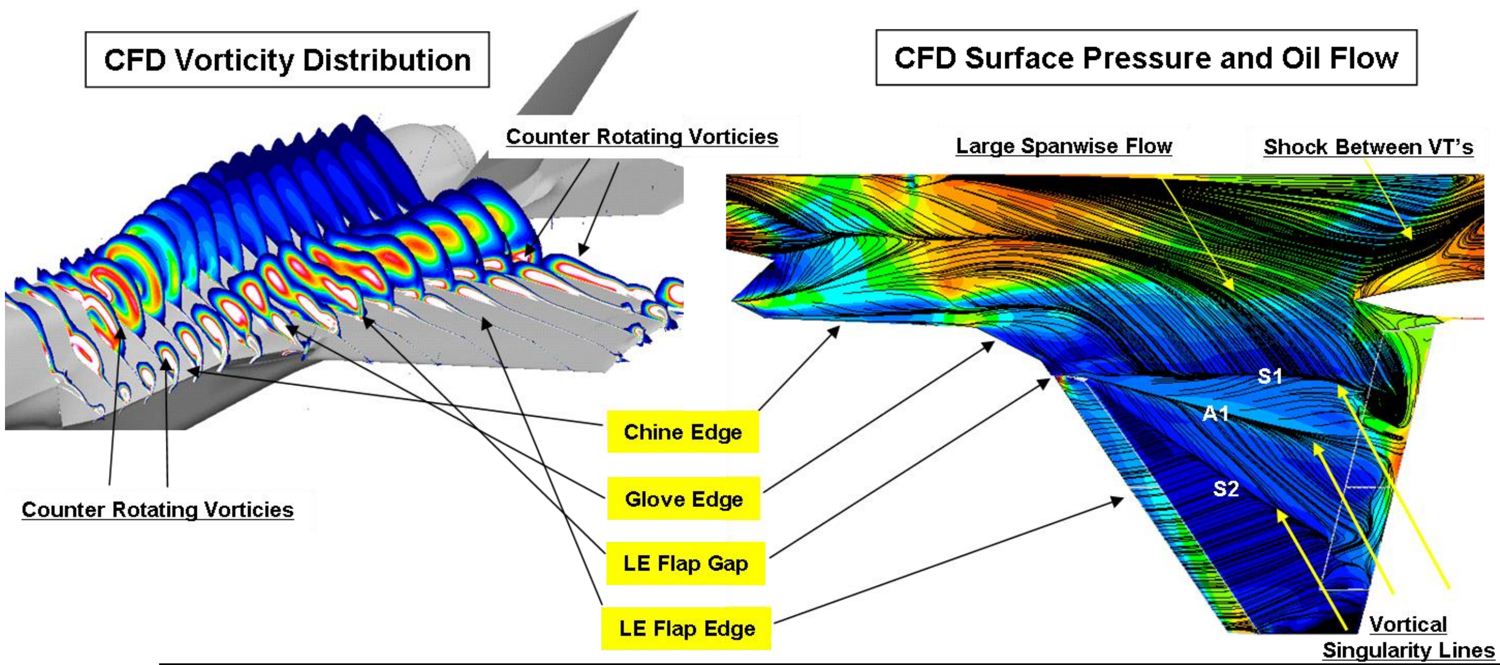
High Fidelity Simulations Required to Analyze Flows with Complex Phenomena

- Some cases require capturing flow physics as accurately as possible
  - Critical flight conditions where an aircraft problem is identified
  - Complex, interacting flow phenomena
    - Shocks
    - Separated flows
    - Vortices
  - Capture of unsteady flow phenomena is required for some problems
    - Aero-optics
    - Aero-acoustics
    - Flow control
- For RANS, need highly accurate models and numerics
  - Explicit algebraic stress or RS closure turbulence models for RANS
  - Extensive model validation
- For unsteady simulations, high order, low dissipation methods
  - Hybrid RANS/LES
  - LES

Advanced Development Programs

For Program Support, Accurate and Efficient Methods Needed

- Program demands high accuracy
- Configuration not changing rapidly
- Many solutions required – database generation – loads, S&C
  - Man-in-the-loop grid generation may be desirable
  - Accurate physical modeling



Advanced Development Programs

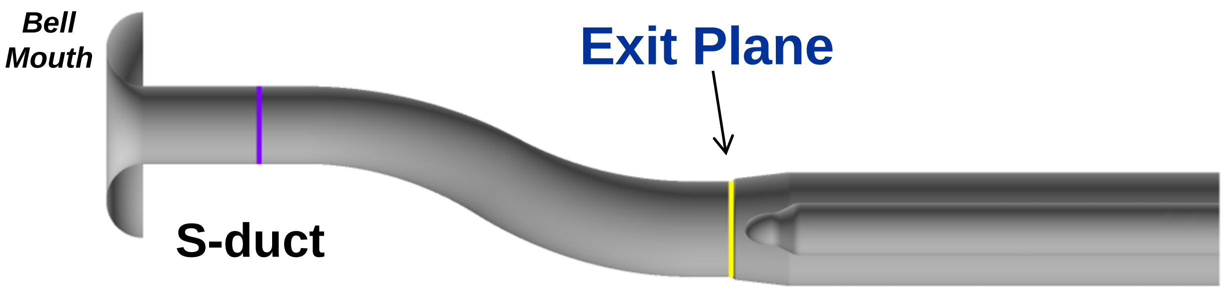
Wooden, Smith and Azevedo, CFD Predictions of Wing Pressure Distributions On the F-35 at Angles-of-Attack for Transonic Maneuvers AIAA 2007-4433

Physical Models are Critical to CFD Accuracy

- We are decades away from being able to use large eddy simulation for routine design applications
- Physical models, and efficient algorithms to solve models, are essential to expanded application of CFD
  - Transition prediction
  - Turbulence modeling – separated flows, compressibility
  - Combustion modeling
  - Real gas reactions for hypersonic flow
  - Flow control actuation
  - Icing
  - Ablation
  - …

Computational Methods Have Improved, Modeling Issues now Leading Error Term

- **Propulsion Aerodynamics Workshop found turbulence models to be largest source of differences between predictions**
  - **Next pages show results for different turbulence models and different flow solvers with a range of grid densities and solutions algorithms**
  - **Results show the total pressure recovery near the exit plane**

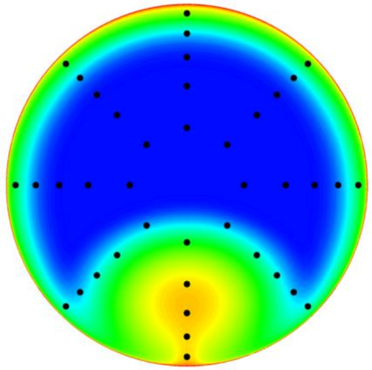


From Domel, Baruzzini and Tworek, "Inlet CFD Results: Comparison of Solver, Turbulence Model , Grid Density and Topology," AIAA 2013-3793

Results: Solver 1, 2-eq

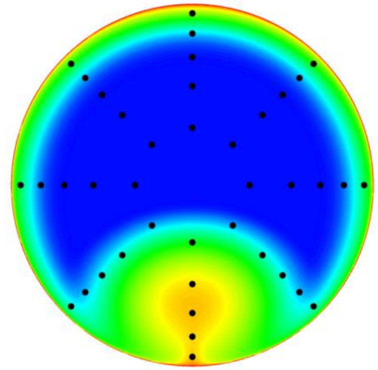
Structured

Hex (Coarse)



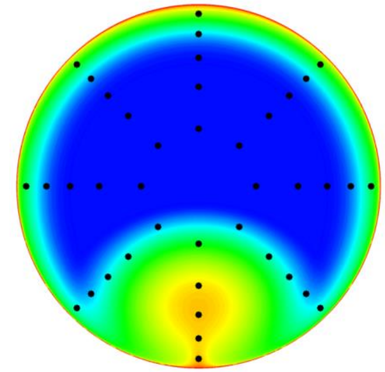
Δ % Recovery	**+0.56**
Δ % DPCP40 ave	**+0.38**

Hex (Medium)



Δ % Recovery	**+0.58**
Δ % DPCP40 ave	**+0.39**

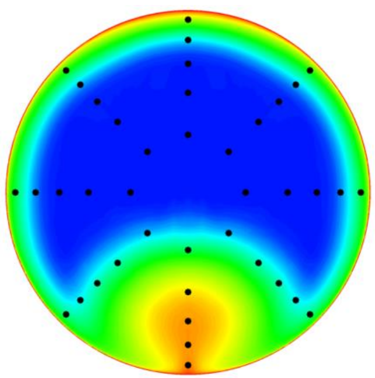
Hex (Fine)



Δ % Recovery	**+0.58**
Δ % DPCP40 ave	**+0.40**

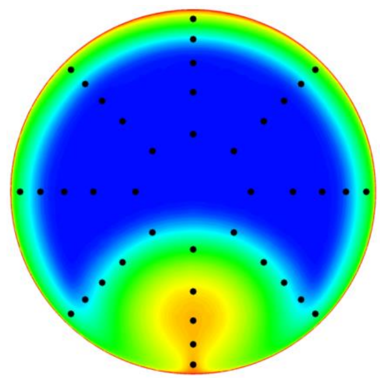
Unstructured

Tet Prism (Very Coarse)



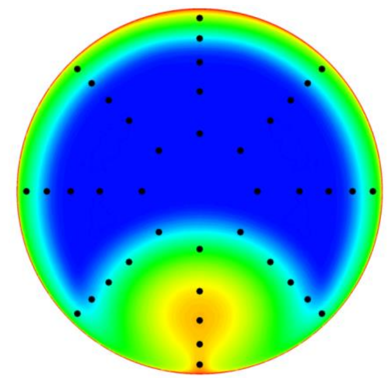
Δ % Recovery	**+0.33**
Δ % DPCP40 ave	**+0.41**

Tet Prism (Medium)



Δ % Recovery	**+0.53**
Δ % DPCP40 ave	**+0.42**

Tet Prism (Fine)

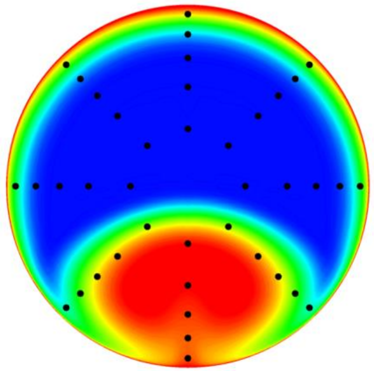


Δ % Recovery	**+0.54**
Δ % DPCP40 ave	**+0.38**

Results: Solver 1, 1-eq

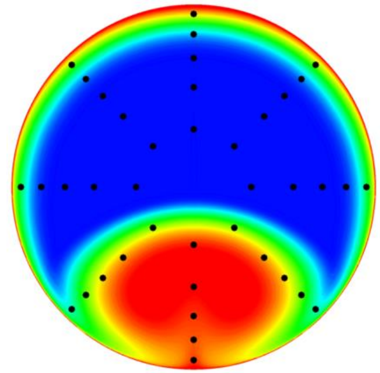
Structured

Hex (Coarse)



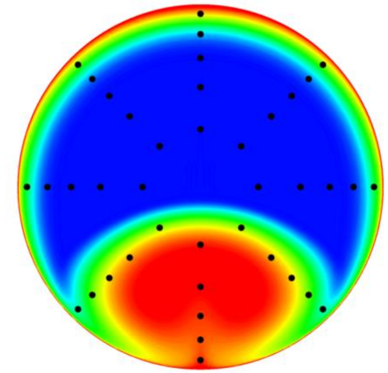
Δ % Recovery	-0.69
Δ % DPCP40 ave	+1.56

Hex (Medium)



Δ % Recovery	-0.67
Δ % DPCP40 ave	+1.57

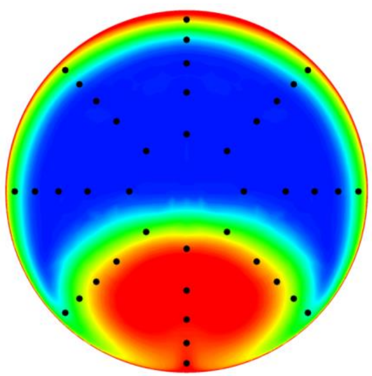
Hex (Fine)



Δ % Recovery	-0.67
Δ % DPCP40 ave	+1.58

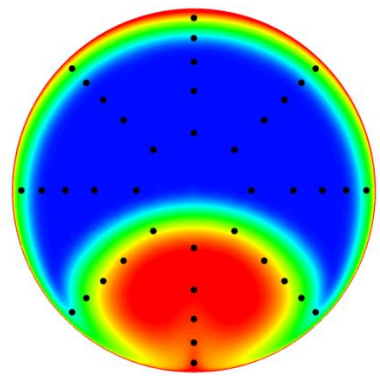
Unstructured

Tet Prism (Very Coarse)



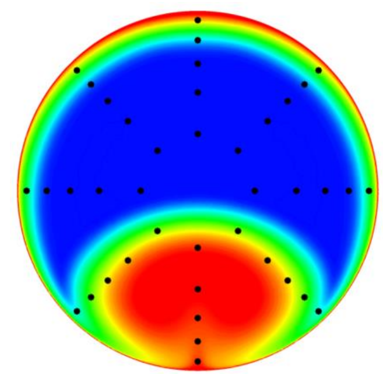
Δ % Recovery	-0.84
Δ % DPCP40 ave	+1.61

Tet Prism (Medium)



Δ % Recovery	-0.64
Δ % DPCP40 ave	+1.63

Tet Prism (Fine)

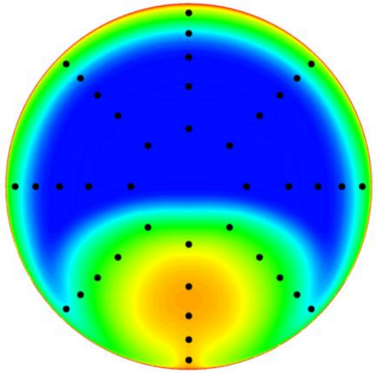


Δ % Recovery	-0.64
Δ % DPCP40 ave	+1.59

Results: Solver 2, K-KL

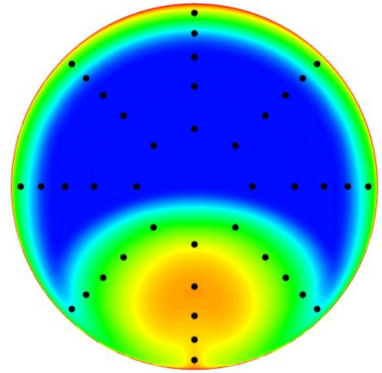
Structured

Hex (Coarse)



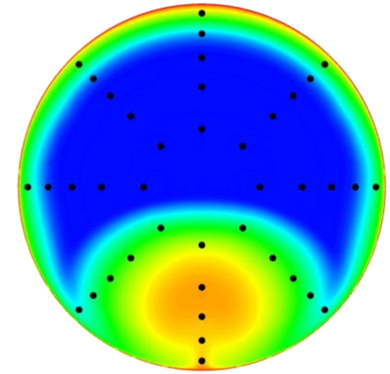
Δ % Recovery	+0.10
Δ % DPCP40 ave	+0.98

Hex (Medium)



Δ % Recovery	+0.06
Δ % DPCP40 ave	+0.73

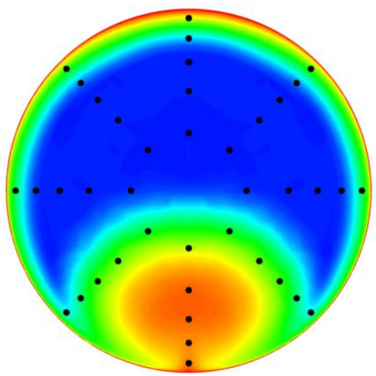
Hex (Fine)



Δ % Recovery	+0.07
Δ % DPCP40 ave	+0.74

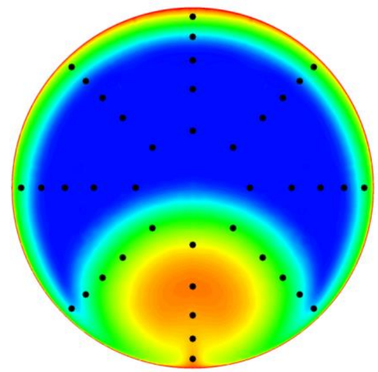
Unstructured

Tet Prism (Very Coarse)



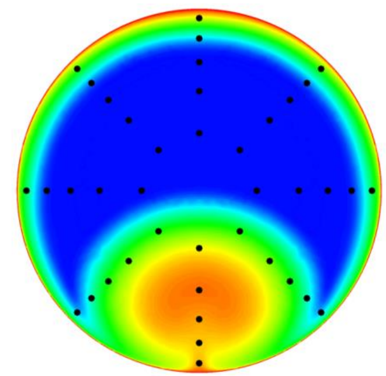
Δ % Recovery	-0.16
Δ % DPCP40 ave	+0.79

Tet Prism (Medium)



Δ % Recovery	+0.07
Δ % DPCP40 ave	+0.83

Tet Prism (Fine)

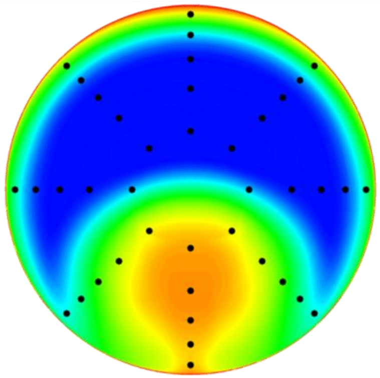


Δ % Recovery	+0.06
Δ % DPCP40 ave	+0.84

Results: Solver 2, ASM

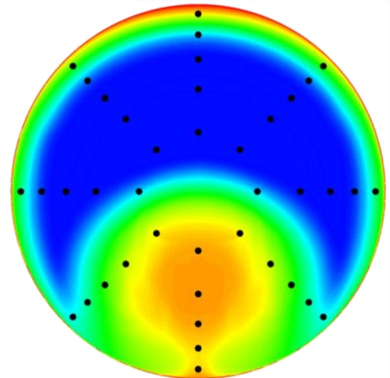
Structured

Hex (Coarse)



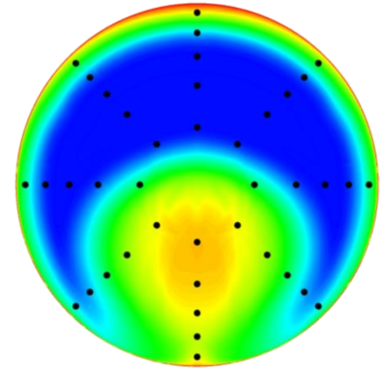
Δ % Recovery	-0.28
Δ % DPCP40 ave	+0.99

Hex (Medium)



Δ % Recovery	-0.28
Δ % DPCP40 ave	+0.98

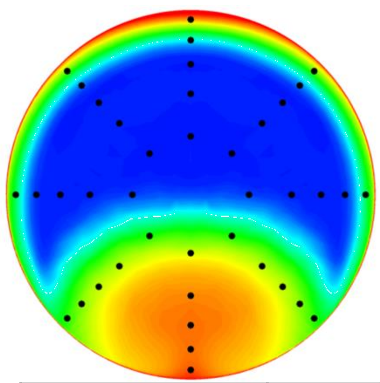
Hex (Fine)



Δ % Recovery	-0.13
Δ % DPCP40 ave	+0.65

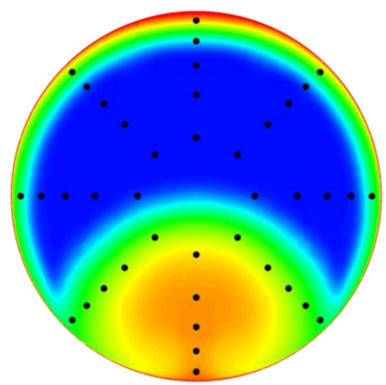
Unstructured

Tet Prism (Very Coarse)



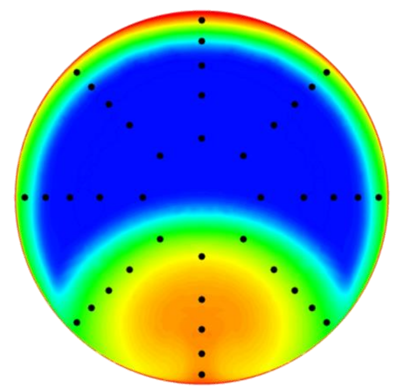
Δ % Recovery	-0.60
Δ % DPCP40 ave	+1.14

Tet Prism (Medium)



Δ % Recovery	-0.40
Δ % DPCP40 ave	+1.12

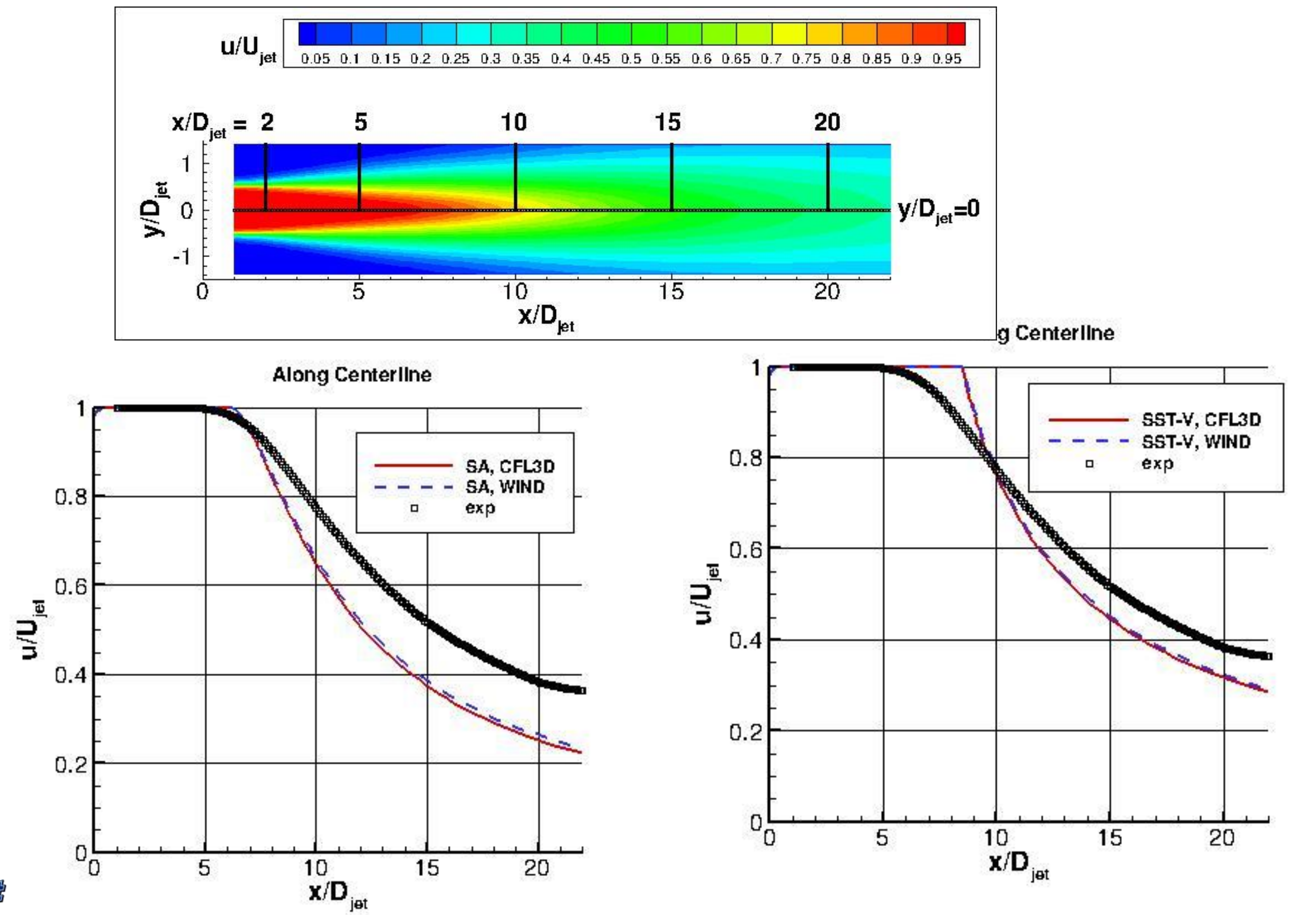
Tet Prism (Fine)



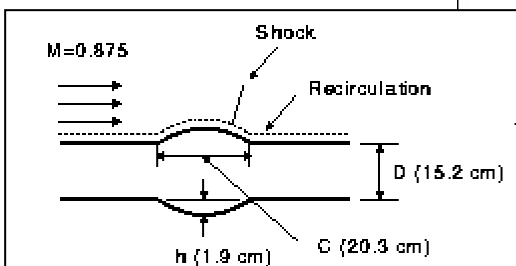
Δ % Recovery	-0.39
Δ % DPCP40 ave	+1.09

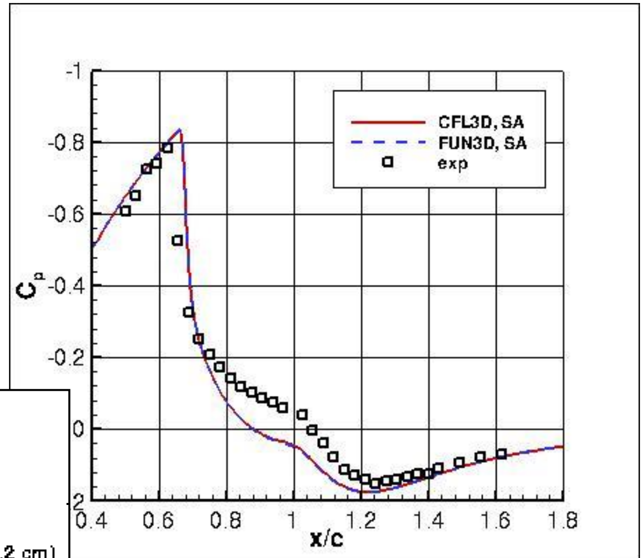
Standard Turbulence Models do not Capture Many Simple Flows Well

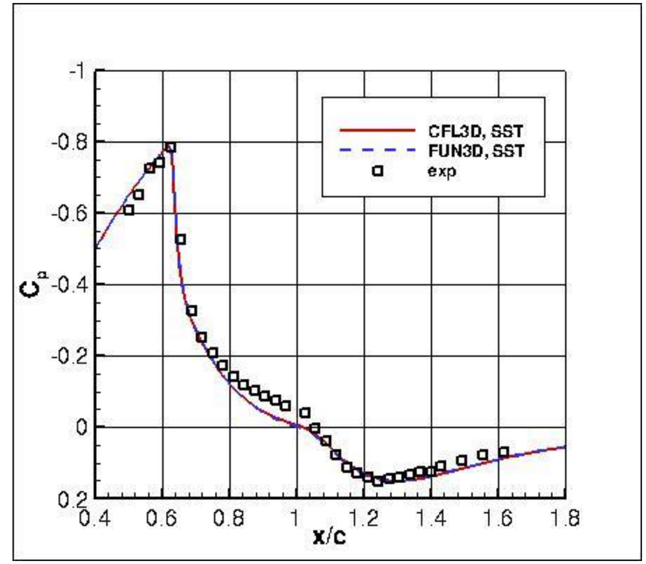
- **Results from AIAATurbulence Model Benchmarking Working Group website for subsonic jet centerline velocity**
- **If these simple flows are not predicted well, what should we expect for complex jet flows?**

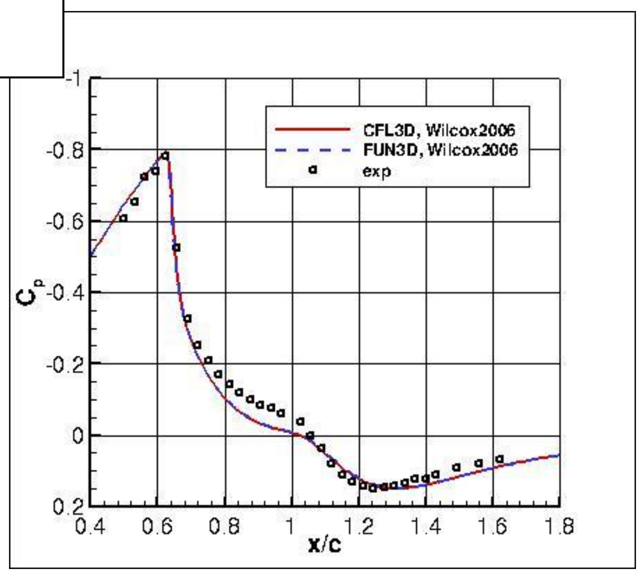


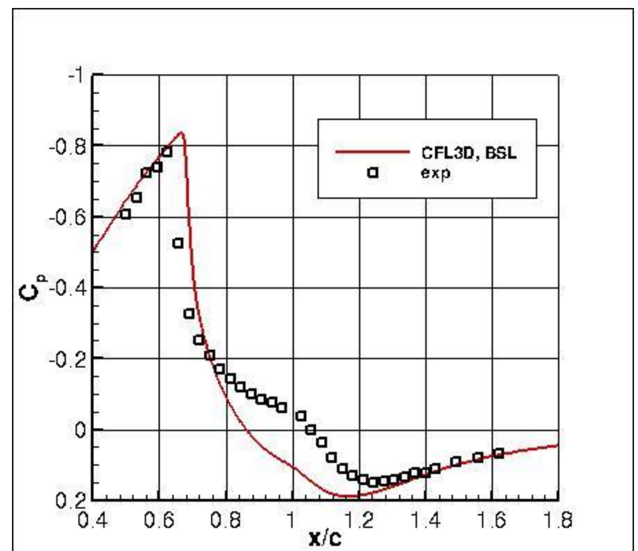
Transonic Flow over an Axisymmetric Bump – Separated Flows Remain a Challenge







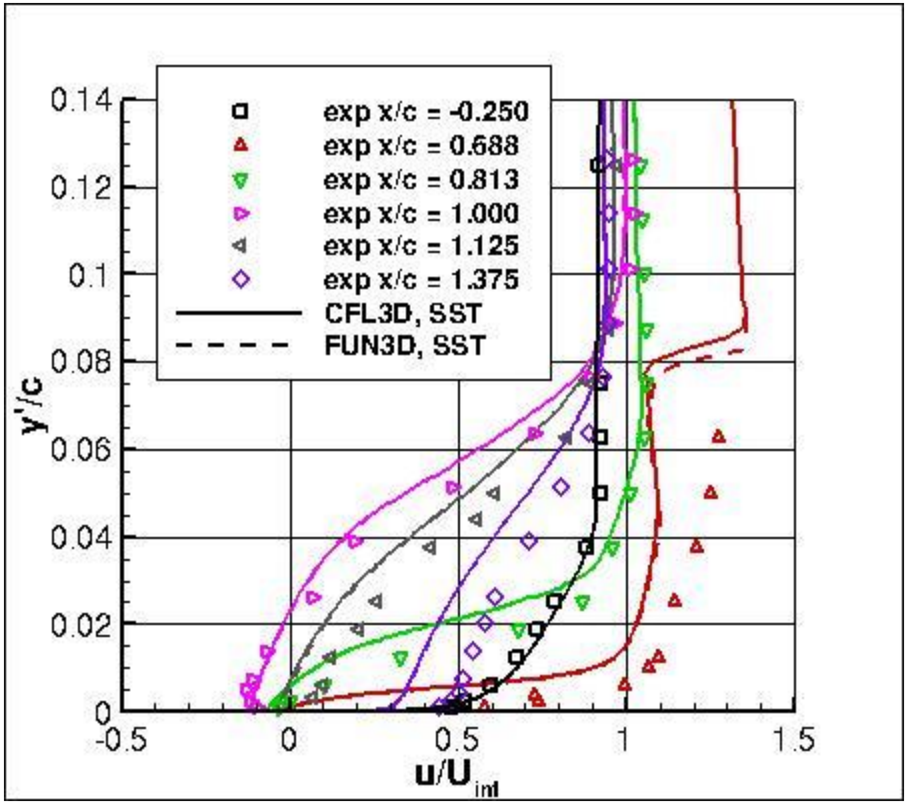


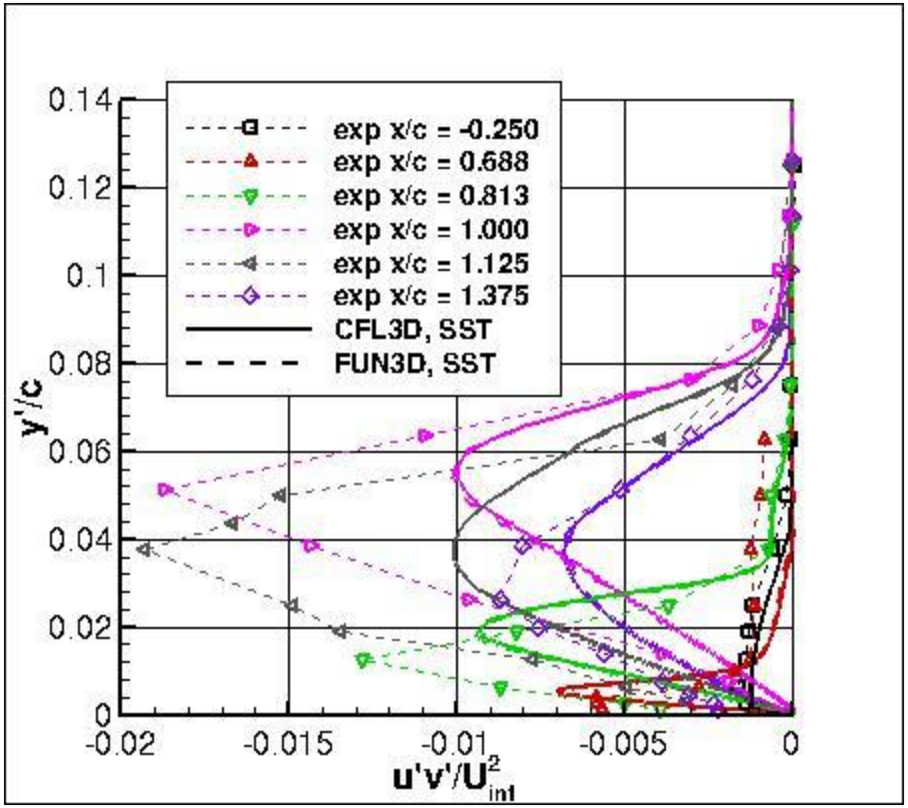


Advanced Development Programs

Velocity and Turbulence Profiles not Predicted Well for Transonic Flow over Axisymmetric Bump

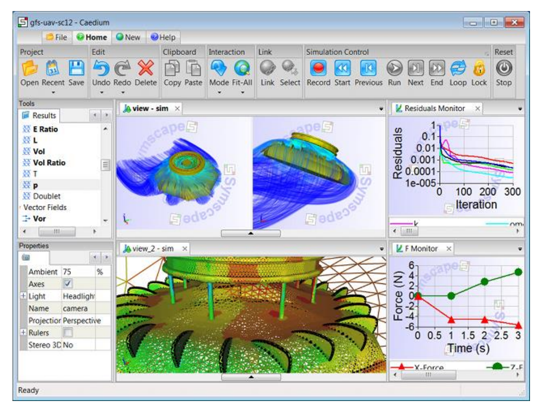
- SST predicts pressure on bump reasonably well
- Velocity and shear stress profiles are poorly predicted
- Results from Turbulence Model Benchmarking Working Group website





Industry has a Need for a Diverse Set of Tools to Meet Diverse Requirements

- **Automated methods needed for preliminary design and optimization**
- **Accurate methods needed for system development and maturation**
- **Common thread – bigger computers alone insufficient to meet needs!**
  - **Increased automation requires investment in software and algorithms for grid generation, flow solution and post processing**
  - **Improved accuracy requires investment in improved physical models of turbulence, and robust high order accurate numerical methods.**



Advanced Development Programs

Wind Tunnel vs CFD on Programs

- Project development efforts have extensive experience using wind tunnel data to develop databases
  - Errors in wind tunnel data have been quantified, corrections developed
  - Process is well defined, results are generally repeatable
- Less experience base with CFD
  - Many error sources not well understood by users or program managers
  - Results can be sensitive to CFD software, grid, models
  - User expertise factor in result quality
- Once a design is matured, wind tunnel based generation of some data bases is more competitive in accuracy and cost
  - Minimal model changes
  - Large data sets can be generated rapidly
  - Off design conditions can be relatively accurate
- Large numbers of CFD runs with a fixed model can require significant computational resources
  - Off design cases may be less accurate (high lift, high angle of attack maneuvers)
  - A requirement for a large database generated using unsteady CFD (hybrid RANS/LES methods) may not be feasible computationally

Advanced Development Programs

Key Factors for CFD for Military Aircraft Environment

- Computational efficiency is important
- Accurate modeling of turbulence, transition, combustion: currently lacking
- CFD methods and physical models have to be selected for each application to obtain acceptable accuracy and performance
- Calibration and validation are an essential part of industrial application for complex flow problems
- Results are dependent on
  - Code
  - Models
  - User competency

Summary

- **Increasing computer power at reduced costs provides opportunities for increased application of CFD**
- **Industrial applications are diverse in terms of level of accuracy and efficiency that are required**
- **Significant improvement in CFD methods is required to harness increased computer power**

Advanced Development Programs